TECHNOLOGY TRENDS IN THE FIRST FIFTY YEARS

G. D. SPEAKE

This paper gives a brief summary of some of the trends in technology which have converted the initial ideas, some formulated as early as the 1920's, to the sophisticated systems developed for a variety of radar roles in use today.

THE ORIGINS

The birth of radar in Britain may be regarded as having taken place on 26th February 1935 when short-wave signals from the BBC's Empire station at Daventry were detected and displayed on a cathode ray tube after reflection from a Heyford bomber. However, it may be argued that conception took place much earlier. As early as 1922, Marconi, when being presented with the Medal of Honor of the American Institute of Engineers, said in the course of his speech "In some of my tests I have noticed the effects of reflection of these waves by metallic objects miles away. It seems to me that it should be possible to design apparatus by means of which a ship could radiate or project a divergent beams of these rays in any desired direction which rays, in coming across a metallic object such as another steamer or ship, would be reflected back to a receiver screened from the local transmitter on the sending ship, and thereby reveal the presence and bearing of ships . . . . .".

What was needed to bring this vague concept to successful demonstration in 1935 and to bring radar to the mature status which it enjoys 50 years later was a series of injections of electronics technology, some of which are described in the various articles which make up this issue.

CH – The First System

The first foundations were laid in ionospheric sounding research in the late 1920's, when both continuous waves and pulses were employed, the work of Breit and Tuve on pulsed systems being particularly relevant to the early development of accurate radar ranging. Some experiments on reception of signals from ground based objects irradiated by pulsed electromagnetic waves were carried out at the Signals Experimental Establishment at Woolwich in 1931, but the detection range was only about 100 metres. (However, it is interesting to note that these experiments and others made by Marconi himself in 1934 used a frequently of about 600 MHz, which was exploited very successfully in the 1950's and subsequently by the Marconi Company for civil radar purposes). By 1935, the techniques of r.f. power generation and reception had advanced sufficiently to enable operationally useful detection ranges to be achieved on aircraft and the provision of the chain of CH stations for UK radar defence was begun. The choice of the h.f. band as operating frequency was made primarily on the basis of available technology, there being considerable experience available from communication and television work. Transmitting antennas were in the form of wire "curtain" arrays strung between steel masts, the responsibility for supply and erection being assigned to the Marconi Company. Simple crossed dipoles on wooden masts were used for reception. This system was capable of giving useful operational data on bearing and angle of elevation of targets, with very good range accuracy, and an experienced operator was also able to assess the strength of an approaching threat from the character of the returned signal as displayed.

Targets at low angles of elevation were difficult to detect because energy received direct from them interfered destructively with that coming by reflection from the earth's surface. Fortunately for the defence system, this point was not immediately apparent to the attacking forces, perhaps because their own radars worked at higher frequencies where ground reflection effects are less troublesome, and most raids were made at relatively high altitude. However, it was clear to the U.K. radar designers that this favourable circumstance would not last indefinitely.

METRIC RADAR

The next development was therefore to take the operating frequency into a higher metric band (around 200 MHz), and to narrow the beam in both planes by feeding arrays of dipoles in parallel to produce a relatively wide aperture antenna. Installation of the system on an elevated site also contributed to an improvement in performance against low flying targets, and coverage over the full 360° of azimuth could be achieved by rotation of the antenna. It was necessary either to synchronise rates of rotation of transmitting and receiving antennas (which was tried for a short time on some stations but proved to be formidably difficult) or to use one antenna for both transmission and reception. This was achieved by use of a TR cell i.e. a device which protected the sensitive receiver during the high energy transmitter pulse, but which recovered quickly thereafter so as not to inhibit reception of signals from short range targets. In its simplest form used with the metric radars, the TR cell was a simple spark gap mounted across the parallel wire feeder between antenna and receiver, but much more sophisticated devices were developed later.

The other technological advance which accompanied the development of metric, narrow beam radars was the Plan Position Indicator (PPI), a cathode ray display with a time base rotating in synchronism with the antenna and a "bright-up" at the range appropriate to a target. It gave to the

operational controller the facility for seeing all aircraft, both attacking and defending, in his area simultaneously, and with it the possibility of controlled interceptions in which relative positions of attacker and interceptor could be continuously monitored.

Metric radars were not only used for low angle cover from land-based stations. Naval versions may still be seen on ships of the Royal Navy and a system operating near ground level on specially selected flat sites gave both plan position and height of targets with sufficient accuracy for ground controlled interception to be initiated. However, beam widths were still relatively wide and ground reflection effects not negligible, so that there was a real need for systems operating at still higher frequencies.

MICROWAVES AND THE CAVITY MAGNETRON

This need was met in 1940 with the emergence, from research work carried out at Birmingham University by Randall and Boot, of one of the most important devices of the war-time period and since, the cavity magnetron. The magnetron as a relatively low power source at operating frequencies up to 3 GHz or so had been the subject of research work in GEC laboratories and elsewhere during the 1930's and within a few months of the announcement of the high power cavity version from Birmingham, it was in production in GEC and shortly afterwards in BTH and Marconi factories. Its use transformed the defence situation in that it allowed long-range radars to be built to give high accuracy and resolution in both horizontal and vertical planes (i.e. for surveillance and height finding) with a low probability of interference. Within a short span of time, the magnetron was in extensive use in land-based, shipborne and air-borne equipment, and it has proved to be as much in demand in peacetime as it was in the war years. Movement into the centimetric bands of the spectrum also caused a demand for new passive components such as waveguides, isolaters, circulators, rotating joints, switches and filters, development of which has evolved continuously from the wartime years – it has in fact resulted in the evolution of a "microwave industry".

SIGNAL RECEPTION AND DATA UTILIZATION

A need also arose for a new input receiver unit capable of converting the centimetric signal to a lower frequency for subsequent amplification, since the wartime technology was not capable of amplifying microwave signals without a major addition of unwanted noise. The solution, which was not superseded until well after the war, was a development of the point contact (cat's whisker) crystal detector of the 1920's, in the perfection of which GEC Laboratories again played a leading role.

In the wartime radars, the man-machine interface was a cathode ray tube and the accuracy of determination of target position depended on the linearity of time bases. High precision in range measurement became possible through technical advances in the generation of linear voltage wave forms and of calibration markers produced by electronic division of frequencies from quartz crystal oscillators. These techniques were employed to great advantage in the Oboe system in which a bomber or "pathfinder" aircraft was placed precisely over a target whether or not the crew had a visual sighting of the ground. The aircraft carried a transponder which made its detection range very much greater than was possible with passive radar and its position was determined by simultaneous range measurement from two ground stations perhaps 100 kms apart.

In the late 1940's after the end of hostilities the impetus for technical advance declined, although some of the earlier developments were modified to adapt them for civil uses such as maritime and air navigation and control of air space. However, by the beginning of the 1950's, interest in military radar was revived and research directed into technologies likely to make radar more effective and less vulnerable in operation. The most dramatic step, in this as in other applications of electronics, was the arrival of the transistor in 1948. Its development in the decade which followed permitted the introduction of many electronic aids to assist the radar operator. These included electronic markers on displays, track-forming techniques, prediction of target movement and collision warning. Thus the scene was set for the future development of computer controlled radar.

POST-WAR RESEARCH

The prime objectives underlying post-war radar research programmes might be listed as 1) the ability to detect and track the smaller and higher speed targets which resulted from developments in aircraft and missile technology, 2) the reduction of the effect of both natural clutter and man-made interference on a radar's performance, and 3) assembly and processing of radar data in such a way as to minimize the need for human intervention and to simplify the task of the system controller – all these requirements being met in an equipment of lowest possible cost and minimum vulnerability.

Progressive advances in target detection capability were made through the development of higher power magnetron and klystron transmitters and of low noise receivers based on travelling wave tubes and (later) solid-state amplifiers. Clutter was reduced by filter techniques which discriminated moving targets from those which were fixed or in relatively slow motion. The first "moving target indicators" (MTI) used an analogue technique, movement being detected by phase comparison of received signals from successive pulses from a radar. The required pulse to pulse delay was achieved by transforming the electro-magnetic pulse to an ultrasonic equivalent, passing it through a liquid delay cell, and re-constituting it for phase comparison with its successor. Later systems embodied much smaller, lighter and cheaper delay cells made from multi-faceted quartz blocks, until such time as solid-state components had reached the stage

whereby the whole process could be achieved digitally. Reduction of the effect of man-made interference was achieved by enabling the operating frequency of the system to be changed rapidly. This requirement for agility demanded the evolution of radar antenna systems in which the beam position was independent of the frequency of operation (so called squintless systems). Other system components such as the transmitting source and the receiver had to be capable of operating over a wide frequency band, and much work by the components' suppliers was devoted to that end.

Another potential means of reducing the effect of man-made interference is to devise a system whereby the antenna can be switched under computer control to concentrate radiated energy in specific sectors which at that moment in time are regarded as particularly important. This can be achieved by the "phased array", in which the antenna is made from many elements the relative phases of which can be controlled by computer instruction, although the cost of making such a system is still prohibitive except in the most demanding situations. An intermediate option is described in the article on Martello in this issue and further advances in microwave integrated circuits and in solid-state amplifiers are likely to lead to more generally applicable solutions.

RECENT TRENDS

Assembly and processing of data has become vastly more effective with the increase in speed and processing capability of digital computers. New processing methods and smaller geometries on semiconductor chips, improvements to processor architectures and better structured software are aiding the radar system controller to meet the more sophisticated threat posed by modern weapons. Artificial intelligence techniques will assist still further by enabling him to build into his system acquired experience and to reduce the problem of human error in conditions of extreme stress.

This highly advanced position has been achieved from the elementary demonstration in 1935 by the systematic application of new technologies to meet a continuously evolving need. This process shows no sign of reaching its conclusion but two contrasting examples of the current state-of-play may make an appropriate end to this foreward. One is Synthetic Aperture Radar, described more fully in a succeeding article, in which extremely high radar resolution is achieved by simulation of a very large effective antenna aperture by electronic storage techniques. The other is H.F. radar in which resolution is regarded as secondary to the requirement to be able to detect targets beyond the optical horizon. Modern technology has made it possible to get far more information from any frequency band than the early experimenters could have envisaged, but it is interesting that after 50 years of technological advance the need for over-the-horizon detection is taking the modern research worker back into that region of the spectrum where it all began.